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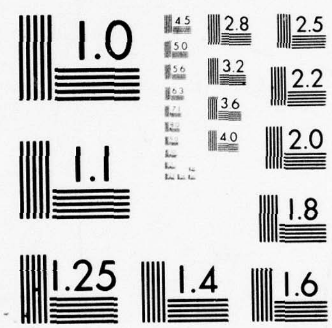
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ONR LONDON CONFERENCE REPORT

C-34-76

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BRANCH OFFICE LONDON ENGLAND

IEE INTERNATIONAL CONFERENCE ON MILLIMETRIC WAVEGUIDE SYSTEMS

Dr. NELSON M. BLACHMAN

19 JANUARY 1977

UNITED STATES OF AMERICA

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At the headquarters of the Institution of Electrical Engineers in London a symposium took place from 9-12 November 1976 on the use of circular waveguides for the long-distance transmission of telephone and related traffic. It served principally as a forum for the presentation of the work of six countries--France, West Germany, Italy, Japan, the US, and the UK--and it included a visit to the UK Post Office Research Centre to see the British 14-km test system as well as devices for its fabrication, measurement,

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installation, and maintenance developed both by the Centre and by its commercial contractors.

This report discusses the six systems, describes equipment seen at the Post Office Research Centre, and reports on some of the 62 papers and the discussions they engendered. Conference sessions were devoted to overview papers, waveguide design and production, routing and laying, characteristics of installed waveguides, rf multiplexing, repeaters, active components and devices, systems aspects, and an open forum.

The British system is intended ultimately to carry 500,000 two-way voice channels in a single 50-millimeter waveguide, and the UK is making plans for the installation of a waveguide system between Bristol and Reading (123 km) with its commercial use scheduled to begin perhaps as early as 1982. French and US plans are not far behind, but Italy and Japan have not yet established schedules, and Germany has decided against the use of a waveguide system on account of its lower rate of growth of long-distance telephone traffic.

IEE INTERNATIONAL CONFERENCE ON MILLIMETRIC WAVEGUIDE SYSTEMS

Introduction

Waveguides owe their origin to the work of Sergei Schelkunoff, George Southworth, and others at the Bell Telephone Laboratory in the early 1930's. Southworth's 1938 patent recognized the possibility of using pipes of circular cross section for the long-distance transmission of microwave signals. A circular waveguide allows these signals to propagate in rotationally symmetric modes TE_{Om} (also designated H_{Om}) whose electric fields are confined to the θ direction and fall to zero at the wall of the waveguide, thus resulting in an unusually low attenuation of the signals per unit distance traveled.

Recognizing the importance of such waveguides for telecommunication, the Institution of Electrical Engineers (IEE) held a convention on this topic in 1959 and a second one (this time designated "conference") in 1970. The third took place at IEE headquarters in London, 9-12 November 1976, with 62 papers representing principally the work of six countries--France, West Germany, Italy, Japan, the UK, and the US. In all three cases the opening remarks were delivered by Professor H.E.M. Barlow (Univ. College, London); this time he observed that plans are now proceeding for the introduction of millimetric waveguides into public service for telecommunications. He expects rapid growth in the demand for the transmission of data and moving pictures, and he feels that services should be provided in advance of the demand, although that is not easily arranged.

Attendance

There were 241 registrants at the Conference--half from the UK; a sixth each from the US and from France; a sixteenth each from West Germany, Italy, and Japan; three people from Yugoslavia; two from the Netherlands; and one each from Australia, Sweden, and Hungary. The Hungarian had been at the University of Braunschweig on an educational-exchange program, where he had, as a student, collaborated in work on the German phase-shift-keying modulator for microwaves. It appears that he is not unique; there have been many others involved in this West German exchange with Eastern Europe despite the difficulties in which participants find themselves on returning to their native lands.

Quite notable was the absence of any participation by the USSR in this Conference. The Soviet Union had participated in the 1970 conference, albeit with the usual (i.e., usual for the USSR--even when attending meetings in Eastern Europe) disregard for schedules and for authorship as an indication of who would come. This time the USSR was invited

to provide a member for the organizing committee, but there was no response whatsoever, just as there was none in connection with the International Symposium on Information Theory held in Ronneby, Sweden, in June 1976. However, five Soviet scientists showed later in June at an international conference on fluid mechanics in Enschede, Netherlands.

Opening Address

The opening address was delivered by J.H.H. Merriman (Board Member for Technology and Senior Director for Development, Post Office Telecommunication Headquarters, UK), who mentioned that field tests in various countries have established the feasibility and economic viability of millimetric-waveguide communication links, but their implementation will be determined by the rate of growth of telephone traffic, which lies between 3% per year for some countries and 27% for others. Data traffic is growing much faster, but at present it forms only a small part of the total; in the future it may become more significant and may even determine the acceptable level of system performance. This growth rate will determine the extent to which waveguides will become part of the world's telephone networks.

At the same time it must be recognized, Merriman continued, that there are four competing technologies, three of which are already in wide use--coaxial cable, point-to-point microwave radio relay, and satellite-borne relay. The coaxial cable is limited to a relatively small bandwidth--about 25 MHz--the microwave spectrum is limited to a larger bandwidth which is already overcrowded, and the necessity of global administration of satellites complicates their employment. Finally, there is the optical-fiber system, which has stirred very wide interest but has yet to undergo adequate life testing, manufacturing-quality control, etc., before any firm plans for its commerical implementation can be made. When optical fibers do come into use, they will probably serve shorter routes than the other media and serve for local distribution in densely populated areas, as they produce a greater attenuation and dispersion per unit distance, thus requiring a shorter spacing between repeaters. These repeaters must in every case recover the original pulses from the digital signal and must produce a new, clean signal in order to keep the effects of noise and various system imperfections from building up and causing errors. Hence, the repeater locations are the places at which to branch out, taking off some channels of information and inserting others.

Millimetric waveguides, in contrast with optical fibers, are now ready for implementation, and the British Post Office is planning to introduce their commercial use in 1982 over the 123-km route between Bristol and Reading. Their waveguide has a 50-mm inner diameter and is "millimetric"

in that it will carry electromagnetic waves of frequencies between 30 and, ultimately, 110 GHz, whose free-space wavelengths lie between 2.7 and 10-mm. These waves travel inside the closely wound, enameled-copper helix (0.122-mmdiam. bare, 0.153-mm with enamel), which forms the inner wall of the pipe. The helix is surrounded by a fiberglass-reinforced lossy epoxy resin (to absorb whatever leaks out through the spurious-mode-suppressing helix) 3.45-mm thick, which is wrapped in an aluminum-foil moisture and gas barrier that, in turn, is wrapped with resin-impregnated tape. This waveguide is placed for protection inside a 105-mm buried steel duct and is installed under tension to allow for thermal expansion.

While all of the waveguides developed in the six countries represented in the program of the conference have inner diameters in the range from 50 to 70 mm, there are great differences in other aspects. Indeed, there is no general agreement as to the format of the information to be transmitted except that it will be digital. The digitalization of a voice waveform is effected by looking at ("sampling") the waveform 8000 times per second and usually representing each observed value by eight binary digits. Because 8000/sec exceeds twice the 3.4-kHz highest voice frequency, these samples suffice for the perfect reconstruction of the voice waveform at the receiving end, apart from the quantization error due to using only 7 or 8 digits. Thus, about 64,000 bit/sec must be transmitted for each voice channel. However, the way in which the bits from the various voice channels are interleaved with each other and with synchronizing pulses differs from country to country, necessitating reformating equipment in the repeater stations at international borders.

With its bandwidth of 80 GHz, Merriman stated, the British waveguide will be able to carry 250,000 voice channels in each direction by means of 250-megabit-per-second binary phase-shift keying (PSK) of 128 different carrier frequencies (64 for each direction). The equipment for this is now ready, he said, and its extension to 500,000 voice channels by the use of 4-phase instead of 2-phase modulation is being studied and will eventually be implemented. The planned Bristol-to-Reading system will begin by utilizing the 30-to-50-GHz band, leaving the higher frequencies for later implementation with perhaps improved techniques as the amount of traffic increases. While the waveguide system has a very high initial cost, it makes additional capacity available very cheaply in this way.

Visit to Post Office Research Centre

Before continuing the discussion of the papers presented at the Conference, it is relevant in connection with the foregoing system to say something about the visit that took place on the last day of the meeting. This visit, on Friday 12 November, to the Post Office Research Centre, Martlesham Heath, Suffolk, (6 miles east of Ipswich, which is 69 miles northeast of London) provided an excellent opportunity for informal discussions and

for seeing the actual equipment used for testing, installing, repairing, and operating the Centre's 14-km waveguide test link to Wickham Market, some 12 km north of the Centre.

In his welcoming address, C.A. May, the Centre's Director of Research, remarked on the importance of exporting to the survival of the United Kingdom, hinting thereby that such things as the millimetric-waveguide system developed by the Centre might provide products for sale abroad. It appears, according to others, however, to have been developed to fill the needs of Britain, and no particular export market for it seems to have been identified, although Italy is experimenting with 400 m of the British waveguide among others.

Exhibits

Among the two dozen demonstrations exhibited at the Post Office Research Centre were the following. Four sources of simulated, plesiochronous 120-megabit-per-second (Mbit/sec) traffic were multiplexed together to form two synchronous digital data streams, each at 249 Mbit/sec. These were transmitted via four-phase modulation through the waveguide to Wickham Market and back to Martlesham from the repeater located there. At Martlesham the two original streams were demultiplexed into the original four 120-Mbit/sec streams. One of these carried prerecorded speech signals, two others carried random bits whose transmission errors could be counted, and the fourth was a digitalized color-TV signal with 8-bit 13-MHz sampling at three times the color-subcarrier frequency. The reproduction of the TV picture was excellent, but it could be degraded by the introduction of attenuation into the waveguide path.

To avoid the oxygen absorption at 60.5 GHz and the small overall attenuation due to water vapor, the waveguide is filled with dry nitrogen at half an atmosphere, and the purity of the gas within the guide and the gas bled from it is monitored along with the pressure. Changes will indicate not only the occurrence of a fault in the duct (and/or the waveguide) but also its location.

A surprisingly simple and accurate device was on display which had been used for measuring the curvature and diameter of the installed waveguide. It was an induced-voltage displacement transducer that was blown by compressed air all the way into the waveguide and was then pulled slowly back by its umbilical cable, making measurements with an accuracy of 0.2 μm by means of a leaf-spring feeler carrying a magnetic core that thus moves between differential windings as the feeler slides along the inner surface of the waveguide.

The gauge carries four such feelers in one plane and four more in the perpendicular plane as well as a pendulum and a resolver to indicate

the orientations of these planes. Curvature is determined from three such measurements over a beam length of 200 mm, while diameter is determined from the middle of these three along with another diametrically opposite it. The curvature in each plane can thus be found down to 5 x 10^{-5} radian per meter by this gauge. If the middle feeler were exactly in the middle of the 200-mm beam, however, there would be no response to periodic variations having a period of 0.1 m. Since components with spatial frequencies up to 12 cycles per meter are able to cause mode conversion and, hence, attenuation of the desired TE_{01} mode (reflecting the difference between the velocities of the modes), the middle feeler is moved 10 mm off center to eliminate this null in the gauge's response.

The measurements are read out once for each 4 mm of travel of the gauge, this being often enough to avoid any problem of "aliasing," i.e., mistaking rapid variations in curvature or diameter for slower, deleterious ones. The measurements are then processed by a fast Fourier transform in order to get the power spectral densities of the diameters, curvatures, etc., as these are the quantities that determine the waveguide's attenuation at each radio frequency. Reasonable agreement is found between the attenuations predicted in this way and those that are measured, due corrections having been introduced for the spatial frequency response of the eccentric virtual chordal-height gauge and for the bending of the waveguide under the weight of the gauge.

On display also was a 90° bend with a radius of 1.3 m showing a remarkably small attenuation, generally falling between 0.1 and 0.2 dB, and for no frequency in the 30-to-110-GHz band of interest exceeding 0.5 dB. It makes use of 18-mm dielectrically lined waveguide, to which 0.5-m-long tapered helical straight sections are added to couple it to the 50-mm helical guide wherever the route must make a sharp bend--mainly in urban areas. Otherwise, bends of radius 100 m or more will produce acceptable attenuation (of the order of 0.5 dB per radian) and will not unduly stress the steel duct carrying the 50-mm helical waveguide. The German approach to sharp bends, in contrast, is to use a widened square corner with an elliptical mirror set at a 45° angle, as presented by Dr. F. Sporleder (Forschungsinstitut der Deutschen Bundespost, Fernmeldtechnisches Zentralamt, Darmstadt). C.R. South (Post Office Research Centre, UK), who developed the British bend, however, felt that such a corner would produce too much of the TE_{0m} modes with m>1, which have low attenuation like the TE_{01} and are hard to eliminate.

For separating groups of sixteen 0.56-GHz-wide waveguide bands at the receiving ends of terminals and repeater stations and for combining them in the transmitting process, "commutating filters" are generally used. They are based on the principle of adding to and subtracting from the signal on the waveguide the same signal delayed by a time T. The result is two outputs whose responses vary sinusoidally and cosinusoidally with frequency, which and can thus separate the odd-numbered bands from the even-numbered

within each 10 GHz. S.A. Mohammed and Dr. N.D. Kenyon (Post Office Research Centre, UK) exhibited a modified commutating filter (based on Marconi Research Laboratory work) for use in the first stage of the separating process (ordinary commutating filters are used beyond it, as adjacent channels are then already removed, and the disadvantages of the sinusoidal response are then much less serious). It uses four instead of two 3-dB directional couplers, four short-circuited lengths of waveguide instead of a single extra length T in one arm between the two 3-dB couplers, and two shunt susceptances in two of the short-circuited guides. It is able in this way to produce a flat response across each band that it passes and a very large attenuation across the bands it rejects, thereby not only providing a much flatter overall response in the passbands but also a large attenuation of image bands and local-oscillator waveforms.

Participating in the display of equipment and techniques were not only representatives of the Microwave Transmission Systems Division (headed by Mr. C.F. Davidson) and the Materials Division (headed by Dr. S. O'Hara) of the Post Office Research Centre but also numerous people representing the manufacturers who supplied portions of the system to the Post Office: BICC (British Insulated Callendar Cables) Research and Engineering Ltd., BICC Telecommunication Cables Ltd. (fabricators of the 16 km of 50-mm waveguide), Flann Microwave Instruments Ltd. (maker of a high-precision, programmable, 26-to-140-GHz attenuator), Marconi Research Laboratories, Marconi Communication Systems Ltd. (supplier of repeater equipment), Plessey Opto-Electronics and Microwave (manufacturers of 40-to-90-GHz, 200-mW IMPATT oscillators), and GEC's (General Electric Company Ltd.) Hirst Research Centre.

Overview Papers

The opening address was followed by overviews of the millimetric-waveguide systems of the six countries. The French system, as described by Ph. Dupuis (Centre National d'Études des Télécommunications, Lannion), uses 50- and 60-mm helical waveguides made by les Cables de Lyon and by the Société Anonyme de Télécommunications. The latter company and the Compagnie Industrielle des Télécommunications have built the baseband and intermediate-frequency equipment for the French 15-km test link between Lannion and Pleumeur-Bodou, where the satellite ground station is located. This link uses four-phase differential PSK to carry 560 Mbit/sec in the 31-to-60-GHz band.

Dr. F. Sporleder (Forschungsinstitut der Deutschen Bundespost, Fernmeldetechnisches Zentralamt, Darmstadt) reported that the German Post Office has investigated both helical and dielectrically lined waveguides of 70-mm inside diameter. The latter, made by Felten & Guilleaume Carlswerk AG in Köln-Mülheim, use an aluminum tube electrochemically coated with aluminum oxide (thickness 67 μm). At the end of the manufacturing process

this tube is passed through a set of six rollers of carefully designed shapes, positions, and orientations that deform a straight tube only elastically but effect a straightening of any curvature. Although the result is not a perfectly straight tube, the low-spatial-frequency curvature is shifted in this way to higher frequencies, where it causes much less mode conversion and hence much less attenuation. This roller scheme, which was adapted from a British seven-roller straightner for other applications, turned out to be very similar to the approach developed independently at the Bell Laboratories on the basis of an American design. The rollers simultaneously turn out to reduce the ellipticity of the pipe.

The Italian system was described by Professor R. Koch (Fondazione "Ugo Bordone," Rome), who explained that the millimetric-waveguide work has been carried out at the Centro Onde Millimetriche (set up near Milan by the Fondazione) with the collaboration of the Universities of Bologna and Trieste and the firms Società Italiana Reti Telefoniche Interurbane, S.p.A. (SIRTI), Industrie Pirelli, S.p.A., and GTE Telecommunicazioni, S.p.A., all in Milan. This work has involved the manufacture of 50-mm helical waveguides by Pirelli and by GTE Telecommunicazioni and the testing of these along with samples of BICC, Câbles de Lyon, and Sumitomo helical waveguides as well as a dielectrically lined Sumitomo waveguide. Although the testing has not yet been completed, Italy appears to have the potential for commercial use of this medium.

In Japan the tenfold increase in telephone traffic anticipated between 1977 and 1987 (i.e., 27% per year) is deemed to necessitate the implementation of a millimetric waveguide system, although no date for its completion and commerical use has yet been set. The system that has been developed, designated W-40G, covers the 43-to-87-GHz band, using 51-mm waveguide with a 15-km spacing between repeaters (because of the relatively large amount of curvature of the route) and a ratio of 4:1 between the lengths of dielectrically lined and helical waveguide. It will provide 300,000 two-way telephone channels by means of four-phase modulation. The practicability of this system was described as having already been established in Japanese tests over a 22.7-km experimental line, according to the overview paper by Noda, Miyauchi, Shimada, Ishihara, and Seki (Electrical Communication Labs., Nippon Telegraph and Telephone Public Corp.). These tests were carried out with 800-Mbit/sec four-phase repeaters. There was also mention of advanced work, e.g., the fabrication of silcon IMPATT diodes operating at 185 and 285 GHz with 80- and 8-mW output powers, respectively. These advances are deemed to make feasible a waveguide system using the band 40-120 GHz to carry 1.2 million telephone channels.

The WT4 waveguide transmission system developed at the Bell Telephone Laboratories, Holmdel, N.J., described by Dr. W.D. Warters (BTL) and others, uses 60-mm waveguide--99% of it dielectrically lined and the remainder helical for absorption of spurious modes. The preference for the former results from the emphasis in the US on a long spacing (up to 45 km) between

repeaters and the possibility of keeping the route fairly straight as well as the belief that a copper-plated steel tube (lined with 180 μm of polyethylene for mode suppression) can be fabricated more accurately than a helical waveguide. The 14-km test route in New Jersey, however, has many bends of radius less than 100 m and yet has a loss less than 1 dB/km over the entire band from 40 to 120 GHz. It includes 124 274-Mbit/sec repeaters and covers the band 40-110 GHz, using binary differentially coherent PSK and carrying 237,500 two-way telephone channels.

Although the cost of waveguide transmission is only two-thirds that of coaxial transmission with binary phase modulation (and one-third if quaternary modulation is used), the installation and commercial use of a waveguide system in the US are being deferred till the late 1980's, Warters said this is because of the possibilities of using single-sideband microwave-radio transmission, of changing the traffic pattern to even out the load, and increasing the efficiency of the utlization of resources afforded by computerized record keeping, and because of the present economic slowdown. Much of the very thorough BTL and Western Electric work has evidently been independently duplicated in various countries. Such duplication is necessary, however, not only because the telephone systems: and economic and geographic conditions differ from country to country (e.g., in regard to the cost of acquiring rights of way, which is very large in the US) but also in order to gain experience with the many facets of the new medium.

Discussion

After the overview papers came sessions on waveguide design and production, routing and laying, characterization of installed waveguides, rf multiplexing, repeaters, active components and devices, and system aspects. Each group of six talks filled a period like 0900-1030, 1100-1300, 1430-1600, 1630-1800, or 1830-2000, with the intervals in between for coffee, lunch, tea, or a quick nip at the IEE bar. During the discussions that followed some of the papers or groups of papers, interesting exchanges took place. For example. R.D. Tuminaro (BTL) was asked whether there was not some resistance by the manufacturer of the waveguide to the specification of limits on the power spectral density (PSD) of its curvature--a rather unusual concept for the fabrication of steel pipe. He replied that, although power spectral density was a concept not readily grasped by the vendors or even the buyers of the pipe, they came to appreciate it as its use permitted the acceptance of lots that would otherwise have been rejected. Moreover, the periodicities in waveguide curvature showing up via the PSD were found to correspond to remediable flaws in the manufacturing process that could thus be corrected quickly, increasing the yield of the manufacturing process as well as improving the quality of the product in real time, since the PSD was evaluated by a minicomputer on the production line.

In a discussion of the accuracy with which attenuations can be measured, C.R. South (Post Office Research Centre, UK) and Dr. F. Sporleder (Forschungsinstitut der deutschen Bundespost beim FTZ, Darmstadt, West Germany) concurred in the finding that the remarkably low rms error of 0.01 dB is achieved in the work of their respective groups.

Only a small proportion of the papers presented at the Conference seemed to have originated independently of their countries' waveguide-communication-system projects. One of these was that of Dr. J.D. Adam and Professor J.H. Collins (Edinburgh U.), dealing with the use of magnetostatic-surface-wave delay lines as a means for canceling at IF the delay dispersion associated with TE_{01} propagation in the waveguide (IEEE Trans., *MAG*-10, pp. 783-786 (1974)). The propagation in a planar epitaxial yttrium-iron-garnet (YIG) film subjected to a transverse biasing magnetic field is able to provide a delay closely linear in frequency over the band from 1 to 1.5 GHz, this being the magnetic analogue of the surface-acoustic-wave delay line. The YIG grown on gadolinium gallium garnet was chosen as the ferrimagnetic medium on account of its low loss and low demagnetization, which result in a smallest observed attenuation of 30 dB/μsec of delay. The device is very compact in comparison with the folded-tape meander line and is electrically adjustable via the bias field, but its extension to a 1-GHz bandwidth centered at 2.5 GHZ will, Adam stated, require the development of new transduction techniques to excite magnetostatic surface waves on a metalized YIG surface.

Another paper, "Waveguide System for a Very Large Antenna Array," by W. Weinreb, R. Predmore, M. Ogai (speaker), and A. Parrish (National Radio Astronomy Observatory, Charlottesville, Virginia) dealt with the use of waveguides in tieing together a 21-km array of antenna elements being erected in New Mexico. It handles 11 channels within the band 27 to 53 GHz. This was the only paper not related directly to the use of waveguides in long-distance communication systems, but it too involved TE_{01} transmission through a 60-mm circular helical guide, leading to most of the same problems and solutions as the communication application. The waveguide is manufactured in Japan.

The rf-oscillator output powers required by the waveguide systems are of the order of 0.1 w, and a number of papers were devoted to their design. By means of the proton-isolation process, silicon double-drift and GaAs single-drift IMPATT diodes have been produced for this purpose at the UK Post Office Research Centre and by several UK manufacturers. From the observation of a 250-hour mean time to failure (MTF) at 350°C, it is deduced that at 200°C the MTF will be 5 x 10^6 hours (57 years)--predominantly as a result of metal migration from the contacts, which results in a short circuit.

It is interesting that, despite the overriding importance of economics in determining the future of millimeteric-waveguide transmission and despite

the inclusion of an excellent paper on the "Possible Application of Waveguides in the Main Network of the United Kingdom Post Office," by D.J. Beckley and A.C. Pigott (Network Planning Department, Post Office Telecommunications Headquarters, UK), analyzing the present value of the anticipated costs and benefits over the period 1979-2003, there was never at any time any mention of a dollar or sterling (or franc or mark or lira or yen) price for any component or system. Beckley and Pigott's graphs are presented in terms of arbitrary units, perhaps reflecting the considerable uncertainty as to the effects of future inflation. To meet the UK's anticipated growth, the capacity of its network will be doubled by 1984 and tripled by 1989. The costs of the waveguide system are considered to be well enough known for planning purposes; though the picture is clouded by uncertainty as to the costs of the coming 140-Mbit/sec optical-fiber systems and 500-Mbit/sec coaxial-cable systems. In applying optical fibers the UK has the advantage of being able to insert them into existing earthenware ducts, while in the US new steel ducts (for greater security) would have to be installed along new routes. UK planning supposes optical-fiber systems will be available in 1986, but BTL plans anticipate a date a few years beyond that, these perhaps being an optimistic and a pessimistic figure.

In the Conference's closing, discussion session W.K. Ritchie (UK Post Office Research Centre) pointed out that helical and dielectricallly lined waveguide should produce the same attenuation if they have the same dimensional characteristics. Dr. W.D. Warters (BTL) mentioned that the rms diameter variation for helical waveguide is 3 to 5 μm while it is only 1 μm for dielectrically lined waveguide. Hence, the BTL system uses these in the ratio 1:99, attenuation being the prime consideration in the US, where the distances between branching points tend to be large.

While much of the work to date has involved the modulation of intermediate-frequency (IF) carriers followed by their conversion to their proper places in the millimeter spectrum, Warters (BTL) and R.W. White (UK Post Office Research Centre) agreed that the performance and simplicity of IMPATT-diode oscillators and of PIN-diode phase switches make it preferable to modulate directly at the final radio frequency. P. Dupuis (CNET), however, expressed a preference for testing the performance of the system at IF, and France will thus retain IF modulation, though it may switch from differential phase-shift keying to coherent PSK. Professor R. Koch (Fondazione "Ugo Bordone") mentioned that Italy has chosen IF modulation but may go over to RF modulation.

In response to a final and very significant question from the audience, the panel members indicated their countries' schedules for putting millimetric waveguide systems into commerical service. Warters mentioned the period between 1978 and 1986 for a waveguide installation in the eastern US. While field tests are complete in Japan, Dr. K. Noda (Nippon Telegraph and Telegraph Public Grp.) stated that no date has yet been set for commercial operation. Sporleder indicated that a waveguide system is not going to

be put in service in Germany because the foreseeable demand is not growing rapidly enough to justify it, and the available technology twenty years hence may well make this approach obsolete. In fact, construction of the 45-km test system between Darmstadt and Heidelberg, which was begun in 1974, was terminated in 1976. Dupuis said that a French system will begin operation in 1982 or 1986, and Koch stated that Italian field tests have yet to be conducted. The UK, however, seemed most definite about going commercial with waveguides--dates given ranging between 1982 and 1986.

Publication of Proceedings

The proceedings (31 papers) of the 29-30 January 1959 Convention on 'Long-Distance Transmission by Waveguide' are contained in the first 196 printed pages of Supplement #13 to the *Proceedings of the IEE*, Part B, vol. 106. The 29 September - 2 October 1970 Conference on 'Trunk Telecommunication by Guided Waves' produced IEE Conference Publication #71 containing 69 papers in xiv + 364 typewritten pages. It is available from Peter Peregrinus Ltd., IEE Publication Sales Department, Station House, Nightingale Road, Hitchin, Hertfordshire SQ5 1RJ, at a cost of £12.10 inclusing overseas postage. The compressed, two-column typewritten xv + 250-page collection of the papers presented at the present Conference *can be obtained* at this same price from this address.

Through the course of the Conference it became evident that, in the planning and execution of a millimetric-waveguide communication system, a vast number of different problems must be faced and resolved, ranging from the theory of electromagnetic propagation and the fabrication of millimeter-wave diode amplifiers to means for locating, removing, and replacing a damaged section of waveguide in a minimum time. The proceedings of this Conference provide an excellent overall view of millimetric waveguide systems and the variety of approaches that can reasonably be adopted in regard to many of their aspects. These proceedings should be of great value to anyone interested in very wideband long-distance communication or in millimetric devices.

Programme of Sessions (Subject to amendment)

The number appearing alongside the title of the contribution refers to the page on which the text commences.

Tuesday 9 November 1976

10.00 hrs FORMAL OPENING

Chair and Address of Welcome by
Professor H. E. M. Barlow, FRS, CEng, FIEE, FIERE, Fel.IEEE, FIMechE, FCGI,
Honorary Research Fellow, University College, London, UK

Opening Address by
J. H. H. Merriman, CB, OBE, MSc, MInstP, CEng, FIEE, FKC,
Board Member for Technology and Senior Director: Development,
Post Office Telecommunications HQ, UK;
Past President, The Institution of Electrical Engineers

10.30 hrs CLOSE OF SESSION AND COFFEE INTERVAL

11.00 hrs SESSION 1 – OVERVIEW PAPERS

Chairman: R. W. White, OBE

The overview papers are intended to outline the present status of millimetric waveguide system research and development, with particular emphasis on field trial results and progress toward viable operational systems.

This session aims to provide all participants with a broad outline of progress on an international basis.

The following overview papers will be presented:

1 'Circular waveguide in France'
C. Baptiste and Y. Herlent
Centre National d'Etudes des Télécommunications, France

5 'Research on millimeter wave communication in Germany'
Dr. F. Sporleder
Forschungsinstitut der Deutschen Bundespost, Federal Republic of Germany

9 'Italian research on millimetric waveguides systems'
Prof. R. Koch
Fondazione "Ugo Bordoni", Italy

14 'Research and development of guided millimeter-wave transmission systems in Japan'
Dr. K. Noda, Dr. K. Miyauchi, Dr. S. Shimada, Dr. F. Ishihara and S. Seki
Nippon Telegraph and Telephone Public Corporation, Japan

18 'The WT4 waveguide transmission system'
Dr. W. D. Warters
Bell Telephone Laboratories Inc., USA

22 'Millimetric waveguide system research and development in the UK'
C. A. May
Post Office Research Centre, UK

13.00 hrs CLOSE OF SESSION AND LUNCH INTERVAL

14.30 hrs SESSION 2 – WAVEGUIDE DESIGN AND PRODUCTION – 1

Chairman: Dr. P. C. McNeill

26 'Geometric requirements for and fabrication of WT4 waveguide quality tubing'
R. J. Boyd Jr. and D. J. Thomson
Bell Telephone Laboratories Inc., USA

30 'Design and reliability of the copper-dielectric bonding system for dielectric-lined waveguide'
R. D. Tuminaro, E. Schultz and E. J. Wicks
Bell Telephone Laboratories Inc., USA
G. J. Martyniak
Western Electric Co Inc., USA

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Tuesday 9 November 1976 – continued

34 'Development of a continuous circular waveguide'
Dr. P. Bernardi
Centro Studi e Laboratori Telecomunicazioni, Italy
Prof. G. Falciasecca
Università di Bologna, Italy
Dr. A. Ferrentino, Dr. G. Grasso and Prof. E. Occhini
Industrie Pirelli SpA, Italy

38 'Manufacture and installation of circular waveguide'
M. Carratt
Les Câbles de Lyon, France

42 'Helical waveguide – manufacturing – continuous process'
J. Allanic
Société Anonyme de Télécommunications, France

46 'Aluminium waveguide with aluminium-oxide dielectric lining'
Dr. F. Krahn
Felten & Guilleaume Carlswerk AG, Federal Republic of Germany

16.00 hrs CLOSE OF SESSION AND TEA INTERVAL

16.30 hrs SESSION 3 – WAVEGUIDE DESIGN AND PRODUCTION – 2
Chairman: Dr. W. D. Warters

50 'General design principles and performance of the UKPO trunk waveguide'
W. K. Ritchie and G. H. L. Childs
Post Office Research Centre, UK

55 'Prototype development of the UKPO trunk waveguide'
D. J. Rose
Post Office Research Centre, UK
A. J. Moore and D. J. Greene
BICC Research & Engineering Ltd, UK

59 'Production plant for lightweight millimetric waveguide'
A. J. Moore, D. A. Taylor and D. J. Greene
BICC Research & Engineering Ltd, UK

64 'Intentional sharp bends in reduced diameter circular waveguide'
C. R. South
Post Office Research Centre, UK

68 'A compact 90° corner with expanded diameter and elliptic mirror for circular waveguide'
Dr. F. Sporleder
Forschungsinstitut der Deutschen Bundespost,
Federal Republic of Germany

72 'Route planning for dielectric-lined waveguides with optimized bends'
Dr. G. Garlichs
Forschungsinstitut der Deutschen Bundespost,
Federal Republic of Germany

18.00 hrs CLOSE OF SESSION

18.30 hrs SESSION 4 – ROUTING AND LAYING
Chairman: W. K. Ritchie

76 'Route selection and duct installation techniques for the UK Post Office trunk waveguide system'
D. W. Morris and H. R. Mothersole
Post Office Research Centre, UK

80 'Design considerations for installed WT4 waveguide medium'
J. C. Bankert, R. W. Gretter, M. Lutchansky and D. R. Rutledge
Bell Telephone Laboratories Inc., USA

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Tuesday 9 November 1976 – continued

84 'Installation of the UK Post Office field trial waveguide'
A. Franklin
Post Office Research Centre, UK
T. G. Murphy
BICC Telecommunication Cables Ltd, UK

88 'Laying technology tests in the Italian field trial'
Dr. L. Lo Vecchio
Fondazione "Ugo Bordoni", Italy
Dr. G. Magni
Società Italiana Reti Telefoniche Interurbane SpA, Italy

92 'Pressurization, fault location and repair techniques for the UK Post Office waveguide system'
A. Franklin, Dr. R. P. Bomer, J. R. Watson and T. A. Evans
Post Office Research Centre, UK

20.00 hrs CLOSE OF SESSION

Wednesday 10 November 1976

09.00 hrs SESSION 5 – CHARACTERISATION OF INSTALLED WAVEGUIDES
Chairman: Prof. Dr.-Ing. H.-G. Unger

96 'Mechanical and electrical characterization of installed WT4 waveguide'
D. A. Alsberg, J. C. Anderson, Dr. J. W. Carlin, P. E. Fox, M. A. Gerdine, S. Harris, D. J. Thomson, E. Vignalí, T. J. West, S. D. Williams and D. T. Young
Bell Telephone Laboratories Inc., USA

100 'Waveguide curvature loss: a new mechanism'
Dr. J. W. Carlin and S. C. Moorthy
Bell Telephone Laboratories Inc., USA

104 'The dimensional measurement and the interpretation of the transmission performance of the United Kingdom Post Office field trial waveguide'
P. A. Trudgett and G. H. L. Childs
Post Office Research Centre, UK

109 'A model relating duct curvature to installed waveguide curvature'
Miss G. M. Reid and P. A. Trudgett
Post Office Research Centre, UK

113 'Automated attenuation measurements of the UK Post Office TE_{01} mode circular waveguide field trial route'
Dr. R. P. Bomer
Post Office Research Centre, UK

117 'Characterization of circular waveguide of different manufacture'
Dr. P. Bernardi
Centro Studi e Laboratori Telecomunicazioni, Italy
Dr. F. Bertolani
Fondazione "Ugo Bordoni", Italy
Prof. G. Falciasecca
Università di Bologna, Italy

10.30 hrs CLOSE OF SESSION AND COFFEE INTERVAL

11.00 hrs SESSION 6 – RF MULTIPLEXING
Chairman: S. V. Judd

121 'Optimised band branching networks for millimetre-wave terminal and repeater stations'
Dr. B. F. Nicholson and B. K. Watson
Marconi Research Laboratories, UK

125 'Millimetre-wave commutating hybrid filter with increased selectivity'
R. B. Greed, I. L. Powell and B. K. Watson
Marconi Research Laboratories, UK

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Wednesday 10 November 1976 – continued

128 'Constructional technology of waveguide components for millimetre-wave applications'
B. A. Mills, J. Bodonyi and B. K. Watson
Marconi Research Laboratories, UK

132 'Interference effects in commutating-type channelling filters for the millimetric waveguide system'
S. A. Mohammed and Dr. N. D. Kenyon
Post Office Research Centre, UK

136 'WT4 frequency multiplexing system'
E. T. Harkless, T. A. Abele and H. C. Wang
Bell Telephone Laboratories Inc., USA

140 'Operational millimetric diplexer for waveguide transmission'
Lt. Col. C. E. Rolland
Centre National d'Etudes des Télécommunications, France
G. Le Coz, J. P. Boujet and J. N. Marchalot
Compagnie Industrielle des Télécommunications, France

144 'Frequency multiplexer network using broad band circulators for millimetric waveguide systems'
J. R. Mahieu
Lignes Télégraphiques et Téléphoniques, France

147 'Band diplexing in overmoded rectangular waveguide technique'
Dr. U. Unrau and J. H. Hinken
Technische Universität Braunschweig, Federal Republic of Germany
Dr. F. Sporleder
Forschungsinstitut der Deutschen Bundespost, Federal Republic of Germany
Dr. L. Saad
AEG-Telefunken, Federal Republic of Germany

13.00 hrs CLOSE OF SESSION AND LUNCH INTERVAL

14.30 hrs SESSION 7 – REPEATERS – 1
Chairman: L. Bourgeat

151 'High speed millimetre-wave phase modulators using PIN diodes'
Dr. I. S. Groves, D. R. Borley and B. L. Clark
Post Office Research Centre, UK

155 'Computer simulation of a modem circuit for millimetric waveguide transmission system'
H. Ishio
Nippon Telegraph and Telephone Public Corporation, Japan
Y. Mochida and T. Sakata
Fujitsu Laboratories Ltd, Japan

159 'New aspects in designing microwave PSK modulators'
Dr. K. Schünemann
Technische Universität Braunschweig, Federal Republic of Germany
Dr. F. Sporleder
Forschungsinstitut der Deutschen Bundespost, Federal Republic of Germany
L. Szabó
Hirodaftechnika Sz, Hungary

163 '400 MB QPSK repeater using a modified Costas carrier tracking loop for millimetric waveguide transmission systems'
T. Shimamura and S. Kitazume
Nippon Electric Co Ltd, Japan
S. Seki
Nippon Telegraph and Telephone Public Corporation, Japan

167 'Overall optimisation of channel response in trunk waveguide systems'
P. N. Sargeaunt, Dr. B. F. Nicholson and I. W. Donaldson
Marconi Research Laboratories, UK

171 'Magnetic delay lines for group delay equalisation in millimetric waveguide communication systems'
Dr. J. D. Adam and Prof. J. H. Collins
University of Edinburgh, UK

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Wednesday 10 November 1976 – continued

16.15–16.30 hrs CLOSE OF SESSION AND TEA

18.45–20.15 hrs COCKTAIL RECEPTION
at the Science Museum, Exhibition Road, London SW7

Thursday 11 November 1976

09.00 hrs SESSION 8 – REPEATERS – 2
Chairman: P. N. Sargeaunt

175 'Repeater design and performance in the WT4 system'
P. T. Hutchison, C. E. Barnes, P. Brostrup-Jensen, E. T. Harkless, R. W. Muise and A. J. Nardi
Bell Telephone Laboratories Inc., USA

179 'WT4 line equalization'
R. J. Brown, P. Brostrup-Jensen, J. J. Schottle and P. J. Tu
Bell Telephone Laboratories Inc., USA

183 'Digital transmission experiments on the UK Post Office field trial waveguide'
Dr. N. D. Kenyon, W. H. Holmes and W. J. Clapham
Post Office Research Centre, UK

188 'Repeater equipment proposals for operational waveguide systems'
I. A. Ravenscroft
Post Office Research Centre, UK

191 'Performance of an experimental 264 Mbit/s 2-DPSK guided millimeter wave transmission system at 30 GHz'
Dr. E. Kühn and Dr. F. Sporleder
Forschungsinstitut der Deutschen Bundespost, Federal Republic of Germany

195 'An experimental 528 Mb/s 4-phase DPSK regenerative repeater'
H. J. Heun, Dr. E. Kühn and H. Raubal
Forschungsinstitut der Deutschen Bundespost, Federal Republic of Germany

199 'Digital equipment for a waveguide system'
D. R. Borley and B. K. Woolgar
Post Office Research Centre, UK

203 'I.F. and baseband circuit design and repeater performance'
M. Acx
Société Anonyme de Télécommunications, France
C. Aillet
Compagnie Industrielle des Télécommunications, France
Ph. Dupuis
Centre National d'Etudes des Télécommunications, France

11.00 hrs CLOSE OF SESSION AND COFFEE INTERVAL

11.30 hrs SESSION 9 – ACTIVE COMPONENTS AND DEVICES
Chairman: Prof. A. L. Cullen, OBE

207 'Millimetre-wave oscillators for waveguide communication systems'
P. W. Huish, Dr. I. S. Groves and D. E. Lewis
Post Office Research Centre, UK

211 'Solid state techniques for millimetric waveguide systems'
S. O'Hara, J. D. Speight, P. Leigh, N. McIntyre, K. Cooper and P. O'Sullivan
Post Office Research Centre, UK

215 'Millimetre-wave silicon IMPATT and PIN diodes'
Dr. H. S. Gokgor, A. M. Howard and Dr. J. J. Purcell
Allen Clark Research Centre, UK

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Thursday 11 November 1976 – continued

218 'Double drift silicon avalanche diodes for millimetric applications (26–42 GHz)'
J. V. Bouvet, J. P. Duchemin, R. Funck, J. Obregon and P. Gibeau
Thomson CSF, France

221 'Millimeter-wave signal power amplifiers using IMPATT diodes'
T. Nakagami and N. Tokoyo
Fujitsu Laboratories Ltd, Japan
H. Kato
Nippon Telegraph and Telephone Public Corporation, Japan

225 'Millimeter-wave synthesized sweeper'
N. Kanmuri
Nippon Telegraph and Telephone Public Corporation, Japan
Y. Fujiwara
Hitachi Denshi Ltd, Japan

13.00 hrs CLOSE OF SESSION AND LUNCH INTERVAL

14.30 hrs SESSION 10 – SYSTEM ASPECTS
Chairman: Dr. K. Noda

229 'Synchronisation and multiplexing of digital tributaries for a waveguide system'
D. R. Borley and P. J. Lawrence
Post Office Research Centre, UK

233 'Maintenance and reliability of the WT4 system'
R. P. Guenther, D. A. Alsberg, P. Brostrup-Jensen and W. M. Hauser
Bell Telephone Laboratories Inc., USA

237 'Reliability assurance of a waveguide system by channel switching'
A. G. Stoddart and C. E. Rowlands
Post Office Research Centre, UK

241 'Possible application of waveguides in the main network of the United Kingdom Post Office'
D. J. Beckley and A. C. Pigott
Post Office Telecommunications HQ, UK

245 'Waveguide system for a very large antenna array'
S. Weinreb and M. Ogai*
National Radio Astronomy Observatory, USA
R. Predmore
University of Massachusetts, USA
Dr. A. Parrish
Massachusetts Institute of Technology, USA
*on leave of absence from Furukawa Electric Co, Japan

15.45 hrs CLOSE OF SESSION AND TEA INTERVAL

16.15 hrs SESSION 11 – OPEN FORUM
Chairman: R. W. White, OBE

This session is intended to provide the opportunity for a wide-ranging discussion, with at least one representative from each of the countries contributing to the overview session on the platform.

17.30 hrs CLOSE OF TECHNICAL SESSIONS

Friday 12 November 1976

TECHNICAL VISIT
to the terminal station of the UK field trial, and to various laboratories and experimental facilities related to millimetric waveguide system work, at the Post Office Research Centre, Martlesham Heath, near Ipswich, Suffolk.